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THESIS

AN EVALUATION OF USING THE NOISE-TO-SIGNAL RATIO TO DETERMINE THE SMOOTHING CONSTANT IN EXPONENTIAL SMOOTHING FOR INVENTORY CONTROL

by

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June, 1996

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The author examines the use of the noise-to-signal ratio to develop a simple, yet effective way to choose the smoothing constant. The new adjusted exponential smoothing method is then validated through a series of comparisons with the traditional method of exponential smoothing currently in use for demand forecasting.

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AN EVALUATION OF USING THE NOISE-TO-SIGNAL RATIO TO DETERMINE THE SMOOTHING CONSTANT IN EXPONENTIAL SMOOTHING FOR INVENTORY CONTROL

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ABSTRACT

This research evaluates the use of the noise-to-signal ratio to determine the optimal smoothing constant (alpha) for exponential smoothing for inventory control. As the Navy continues the transition of "right-sizing," inventory managers are faced with fewer personnel and operating funds. Controlling inventory expenditures through an aggressive approach to demand forecasting could be an opportunity to promote efficiency.

The author examines the use of the noise-to-signal ratio to develop a simple, yet effective way to choose the smoothing constant. The new adjusted exponential smoothing method is then validated through a series of comparisons with the traditional method of exponential smoothing currently in use for demand forecasting.

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I. INTRODUCTION

A. OVERVIEW

As the Navy continues to "right-size", inventory managers are faced with doing more with fewer personnel and less financial resources. Given this environment of personnel reductions and decreasing operating funds, controlling inventory expenditures through an aggressive approach to demand forecasting is one of the best opportunities available.

There has been a trend within the military inventory system to utilize exponential smoothing as the primary means of short-term inventory demand forecasting. An exponential smoothing forecast is simple to calculate and requires minimum data to be stored. It calculates a type of moving average where the most recent observations are given greater weight. It stands to reason that inventory managers may want to give more recent historical data more weight and less to older data because that could better reflect the current demand pattern.

Exponential smoothing can average random fluctuations, track trends, and take seasonal influences into account in determining a forecast. As time unfolds, and new actual demand experience is known, it updates the influence which each of these time series components has on forecasted values. While the exponential smoothing model does not directly calculate long-term cyclic patterns, it does, by its very nature, reveal turning points.

B. OBJECTIVE

This thesis analyzes the advantages of utilizing a simplified method of selecting the optimal smoothing constant for use in the exponential smoothing forecasting method. The intent of this research is to help military inventory managers reduce forecast errors and thereby improve inventory management effectiveness. A simple method of choosing the optimal smoothing constant could increase the advantages of using exponential smoothing as the primary method of demand forecasting in the military inventory system.

C. RESEARCH QUESTIONS

The questions examined are as follows:

1) Can the ratio of noise to signal be used to select the smoothing constant?

2) Can an adjusted exponential smoothing approach improve customer service in military inventory management through fewer not-in-stock occurances and reduced excess inventories?

D. SCOPE

The principal thrust of this research is to determine if the noise-to-signal ratio can be used to select the smoothing constant for a given set of demand data and thereby improve inventory management effectiveness. The noise-to-signal ratio is defined as the absolute error divided by the change in the forecast. If a correlation can be found between the noise-to-signal ratio and the optimum alpha value, then a methodology can be recommended to assist inventory managers in forecasting demand using exponential smoothing. This thesis is limited to examining simple exponential smoothing and does not examine the trend-following and seasonal exponential smoothing models.

E. METHODOLOGY

The thesis begins by analyzing the forecasting literature that discusses the various methods of determining the appropriate value of the smoothing constant in exponential smoothing. Next, simulated data is created utilizing the random number function in a Lotus 1-2-3 spreadsheet. Data sets are created with a noise-to-signal ratio ranging from 1 to 56. The optimal smoothing constant is determined for each time series and correlated with the noise-to-signal ratio. This research then shows through case studies how selecting the smoothing constant based on the noise-to-signal ratio could be used in military inventory management.

F. BENEFITS OF RESEARCH

The users of exponential smoothing want a good forecast, minimum data storage requirement, and a simple way to choose the smoothing constant. If large amounts of data are stored in order to optimize the smoothing constant or to calculate a tracking signal, a good forecasting model can be achieved, but at the expense of the advantage of storing a minimum amount of data. If a generic smoothing constant is selected, then the user will have a simple way of choosing the smoothing constant, but the advantage of having a good forecast can be compromised. The problem is to find a simple way to determine an appropriate smoothing constant that will minimize the overall forecasting errors, yet not require the storage of all past historical data.

G. ORGANIZATION OF RESEARCH

The remaining chapters in this thesis are organized as follows: Chapter II discusses the development of the adjusted exponential smoothing model and the generation of simulated data. Chapter III answers the research question: can the noise to signal ratio be used to select the smoothing constant? Chapter IV answers the research question: can the adjusted exponential smoothing approach improve customer service in military inventory management through fewer not-in-stock occurances and reduced excess inventories? Chapter V presents a summary, makes conclusions and provides recommendations concerning the use of the noise-to-signal ratio to determine the smoothing constant for inventory control.

II. NEW FORECASTING MODEL AND DATA

A. CHAPTER INTRODUCTION

This chapter presents the theoretical aspect and actual findings of developing a new way to determine the smoothing constant. A new forecasting model called the "adjusted exponential smoothing model" is developed and applied to demand forecasting. The new model is compared to the traditional simple exponential smoothing model.

The selection process of choosing the smoothing constant, the definition of the forecast error, and the development of the adjusted exponential smoothing model are addressed.

B. SELECTING THE SMOOTHING CONSTANT

Exponential smoothing is a special kind of moving average that does not require a long historical record to be stored and thus reduces the amount of data processing memory and time required. Each forecast includes implicitly all past data weighted exponentially. [Brown, 1959]

Choosing the proper value for the exponential smoothing constant requires judgement. The higher the value of the smoothing constant, the greater the weight placed on the more recent demand. Exponential smoothing requires only two numbers to produce a forecast: the current period's actual demand and the forecast made earlier for the same period. A new forecast is calculated every period by updating the previous forecast with a percentage of the previous forecast error.

The basic exponential smoothing formula can be described as follows:

Next Forecast = Last Forecast + α (Last Forecast Error)

where α is the smoothing constant and

Forecast Error = Actual Demand - Forecasted Demand.

The exponential smoothing model can be expressed mathematically as:

$$F_{t+1} = F_t + \alpha \ (A_t - F_t)$$

where

F_{t+1} = forecast for time period t+1

F_t = forecast for time period t

α = smoothing constant ($0 \leq \alpha \leq 1$)

A_t = actual demand in time period t.

The value chosen for the smoothing constant is between 0 and 1. It determines how much of the past demand effects the estimate of the expected future value. The higher the alpha, the faster the response to changes that occur. The lower the alpha, the slower the response to changes in the data. [Brown]

The choice of the smoothing constant can make the difference between an accurate forecast and an inaccurate forecast. The overall accuracy of a forecasting model can be determined by comparing the forecasted values for past known periods with the actual demand for those periods. [Heizer and Render]

The concept is not complex. The latest estimate of demand is equal to the previous estimate adjusted by a fraction of the difference between the last period's actual demand and its estimate. [Heizer and Render]

C. FORECAST ERROR DEFINED

To the extent that the future is not perfectly mirrored by the past, the pattern of future demand will not necessarily display the same behavior as in the past.

Although there is reason to believe that the pattern generated by a piece of equipment such as a radar transmitter will continue in the future as it has in the past, there is far less reason to believe that a pattern generated by human behavior will continue exactly as it has in the past.

People's behavior does follow general patterns, but people can change behavior and adapt to their environment since they are independent decision-making, agents. Therefore, it can be highly erroneous to assume that the previously observed demand will have a continuing pattern.

In fact, the greatest difficulty in forecasting is that demand patterns (driven by human behavior) change. The changes can be frequent and large. Consequently, to be successful, a forecasting method must be adaptive. [Makridakis, et al]

One measure of the overall forecast error is the mean absolute deviation (MAD). The MAD is determined by taking the total absolute errors of past forecasts and dividing them by the numbers of periods observed. The smaller the MAD, the better the fit to the past data. The optimal α is the value between 0 and 1 that minimizes the MAD.

D. NEW MODEL DEVELOPMENT

To develop the adjusted exponential smoothing model, data was simulated utilizing a Lotus 1-2-3 spreadsheet to generate 100 series of 100 time periods with a signal value of either -1 or 1 (50 each) and noise values ranging from 1 to 50. Figure 1 is an example data set. Simple exponential smoothing was applied to each data set and the smoothing constant was optimized for each by minimizing the MAD.

The 100 optimum smoothing constant values (alpha*) were then plotted versus the noise-to-signal ratio as illustrated in Figure 2. A least squares fit to an equation with exponential decay and a minimum value was utilized to create a fit of the data points. The form of the equation was:

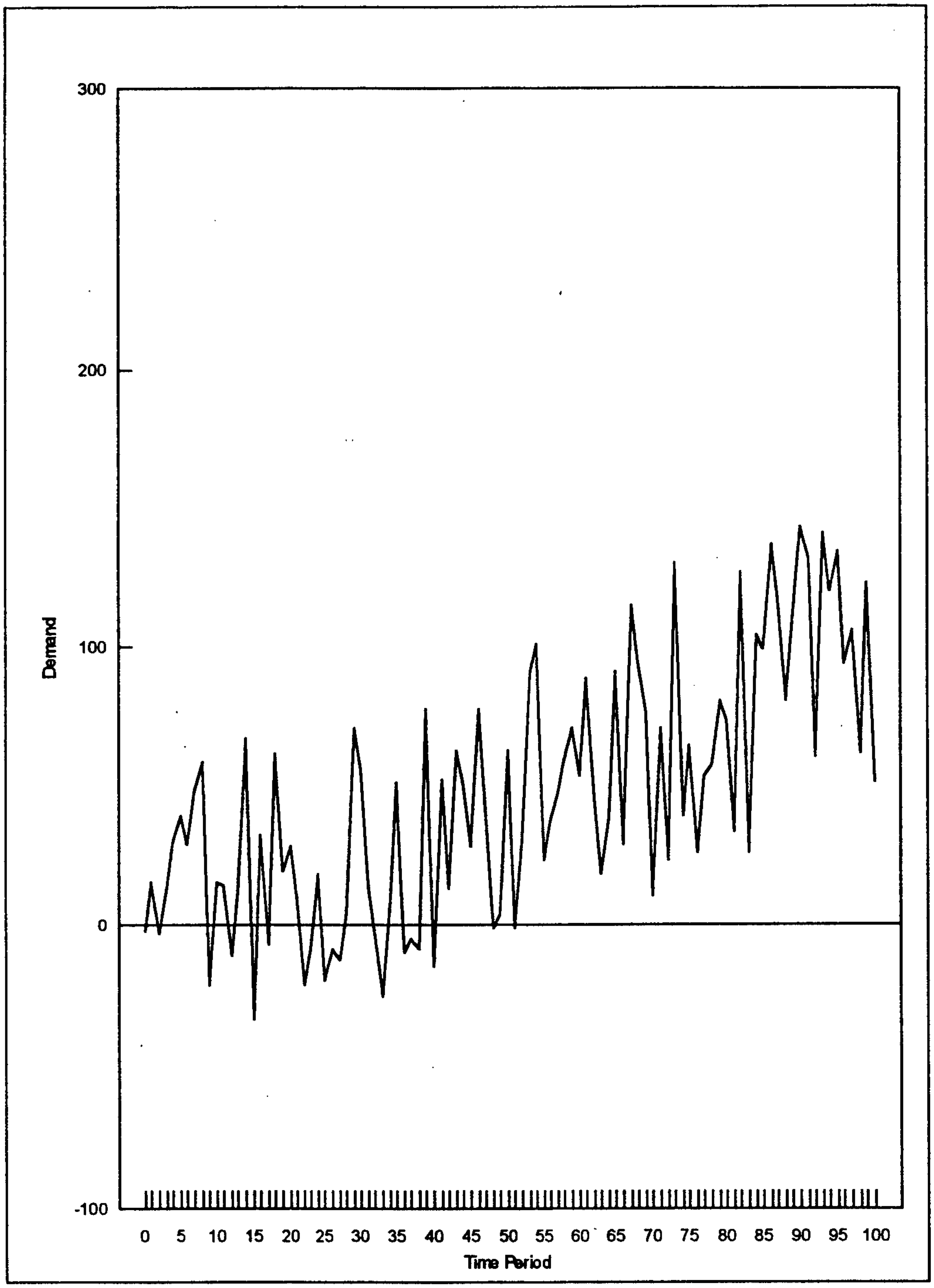
$$y = ae^{-bX} + c.$$

The resulting equation was:

$$\alpha^* = .82\ e^{-.236X} + .18$$

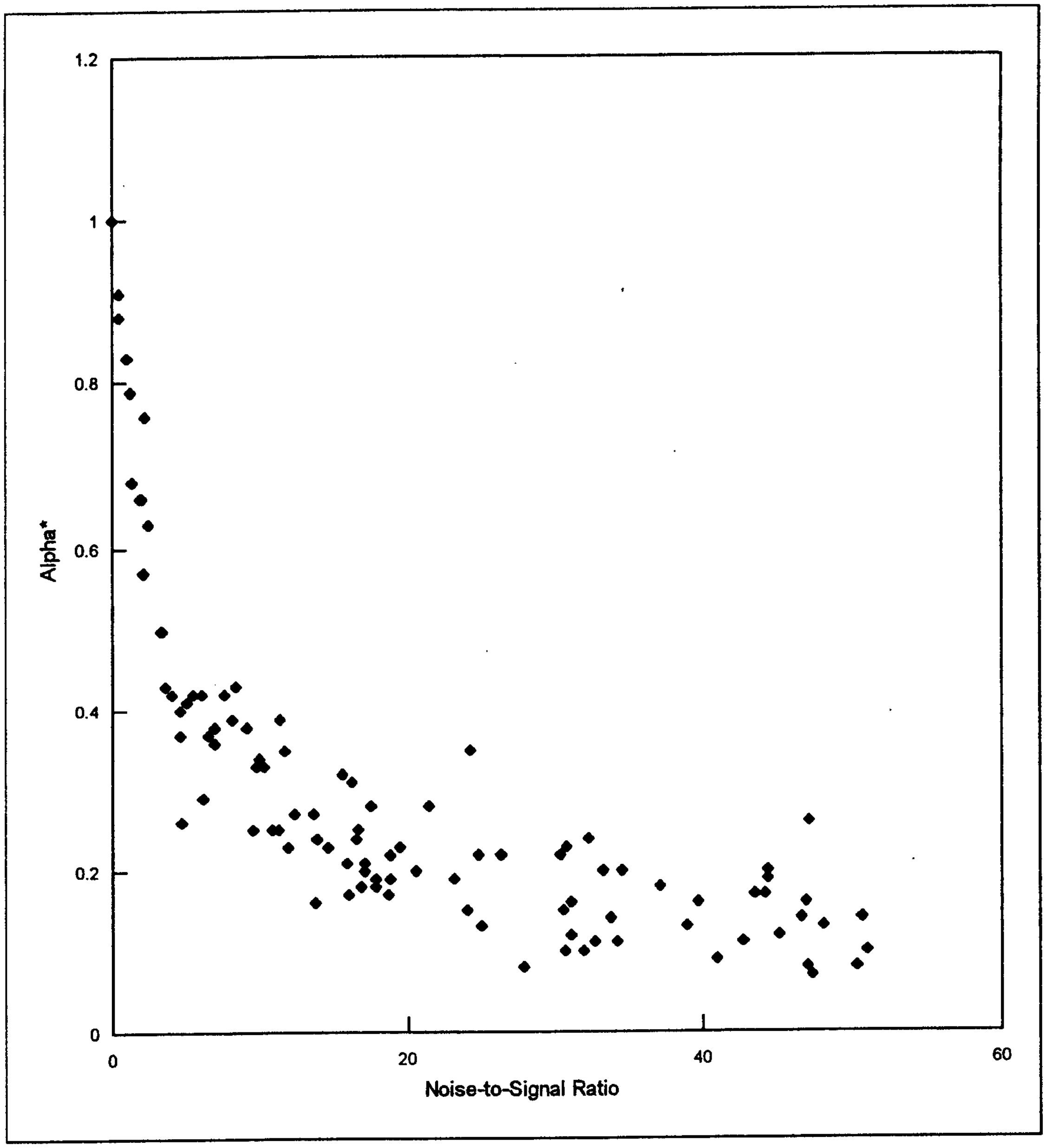
where

X = Noise-to-Signal Ratio.



Simulated Demand Pattern With a Noise-to-Signal Ratio of 29.

Figure 1



Optimun Smoothinh Constant Versus Noise-to-Signal Ratio

Figure 2

The optimal fit correlating the optimal alpha and the noise-to-signal ratio is illustrated graphically in Figure 3. The equation can be used to estimate the optimum smoothing constant in exponential smoothing for a time series with a known noise-to-signal ratio.

E. ADJUSTED EXPONENTIAL SMOOTHING MODEL

The adjusted exponential smoothing model allows the smoothing constant to be adjusted relative to the noise and signal in each time period. The noise is defined as the error in a forecast and the signal is defined as the change in the forecast from the last period. Thus, the adjusted exponential smoothing model becomes:

$$F_{t+1} = F_t + \alpha_{t+1} \ \varepsilon_t$$

where

F_{t+1} = forecast for time period t+1

F_t = forecast for time period t

$\alpha_{t+1} = .82\ e^{-.236X} + .18$

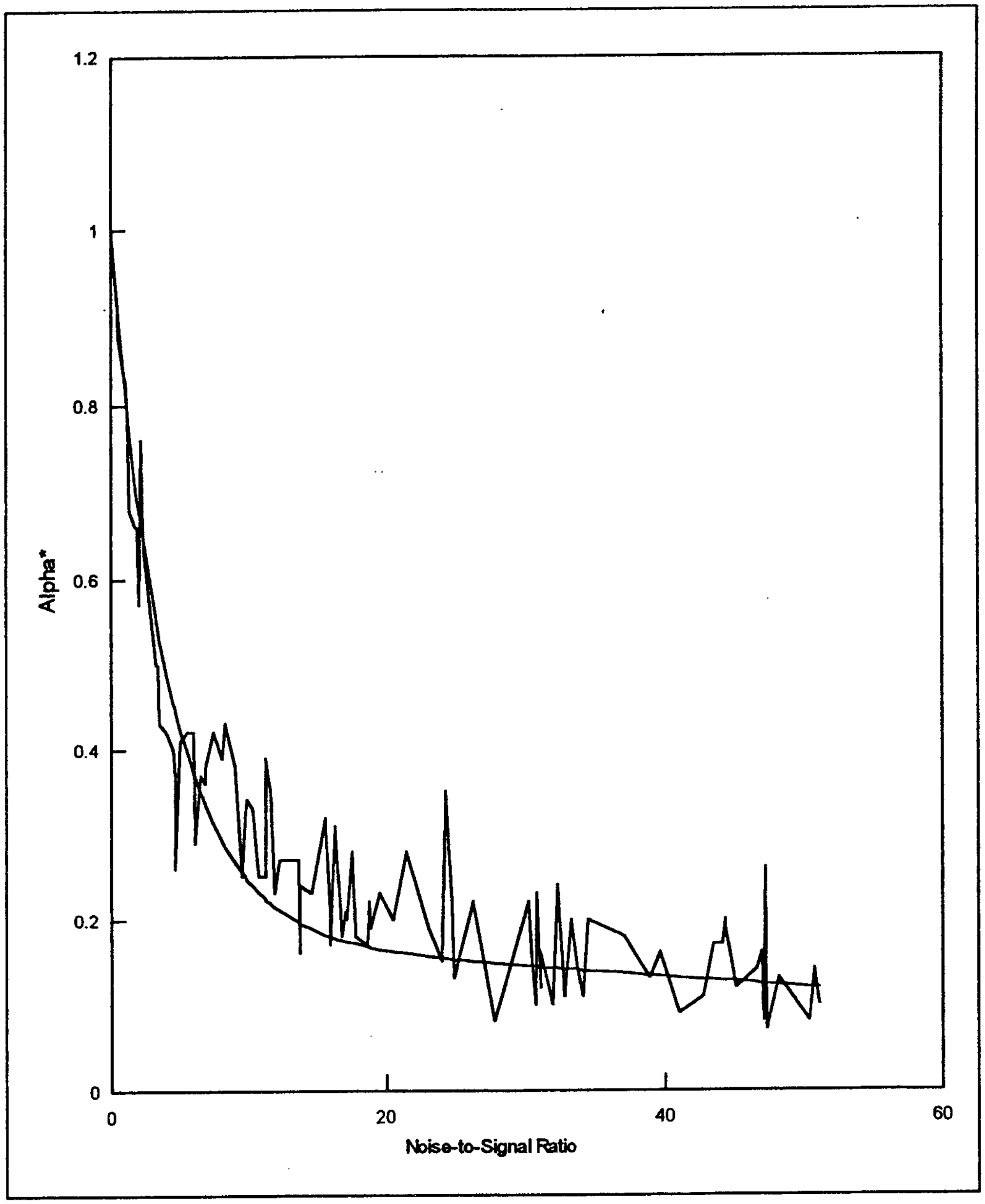
ε_t = absolute error for time period t

X = Noise ÷ Signal

and

Noise = $|\varepsilon_t|$

Signal = $(F_t - F_{t-1})$.



Equation to Estimate Alpha* Given the Noise-to-Signal Ratio

Figure 3

III. DATA APPLICATION

A. CHAPTER INTRODUCTION

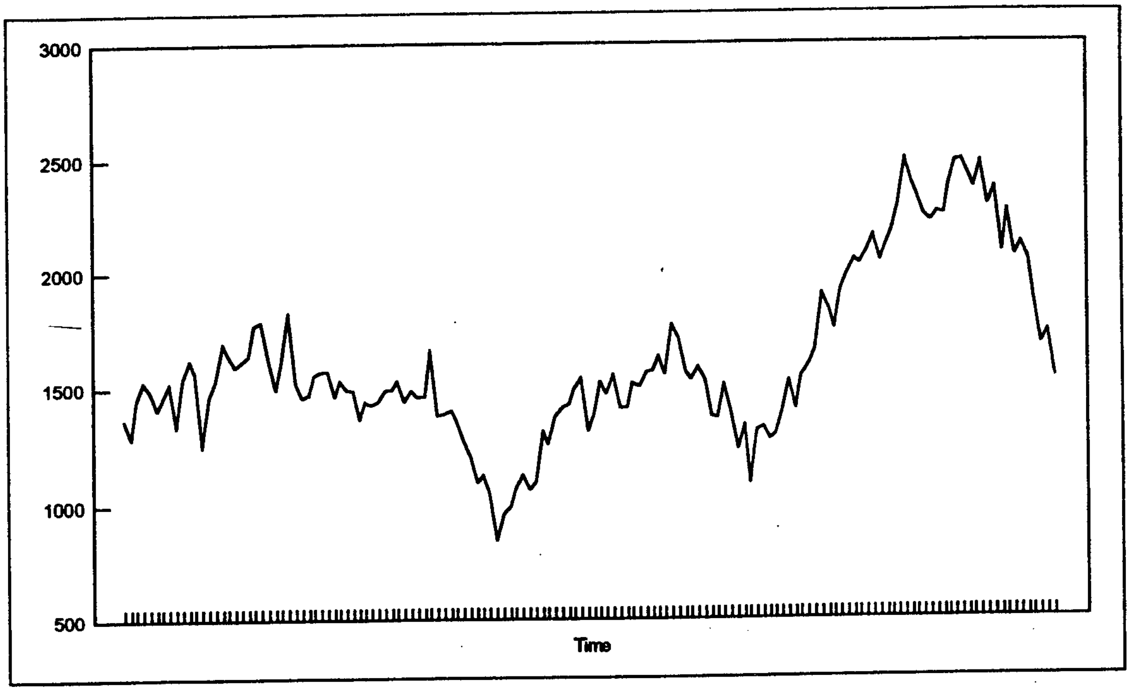
This chapter presents a comparison between the simple exponential smoothing method and the adjusted exponential smoothing method to answer the research question: can the noise-to-signal ratio be used to select the smoothing constant? This analysis was accomplished by applying both methods to simulated and actual data sets.

Two tests were conducted to test the effectiveness of the adjusted method. The first test used a sample of fifty data sets selected from the one hundred simulated data sets that were used to determine the correlation between the optimal alpha and the noise-to-signal ratio for the adjusted exponential smoothing model. The sample was evenly distributed over the range of noise-to-signal values from 1 to 50. The second test used two real demand patterns: 1) one demand pattern with no trend or seasonal elements, and 2) a second with both trend and seasonal elements. Graphs of these demand patterns are shown in Figure 4. These two patterns were selected from the 111 time series discussed in Makridakis, et al.

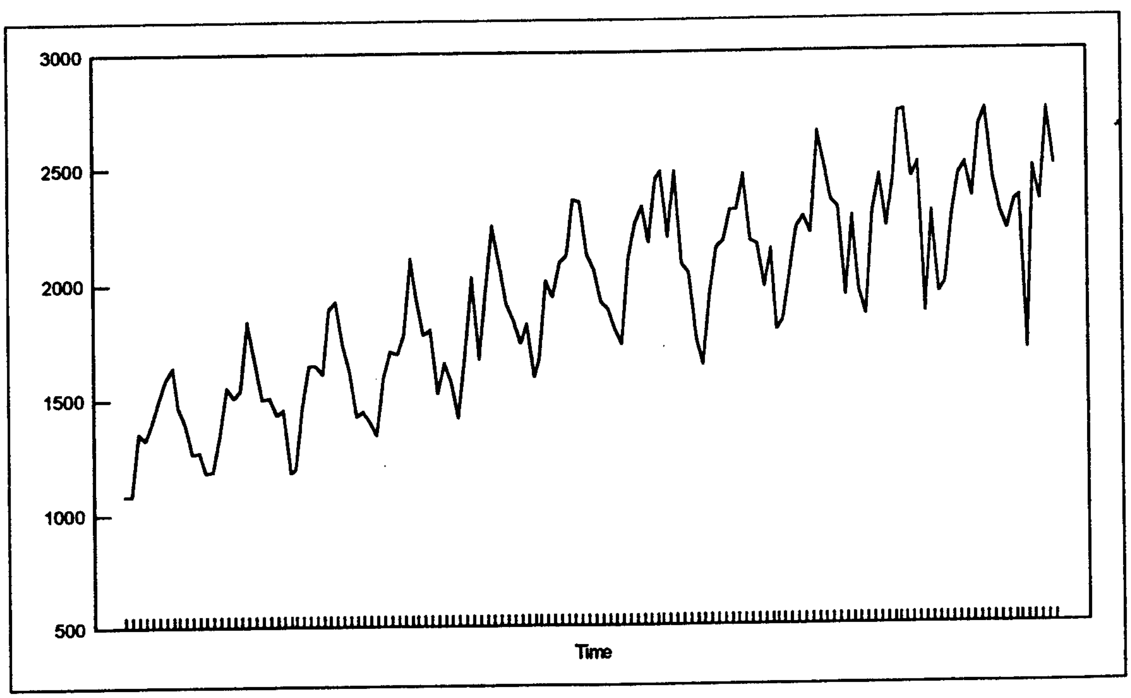
B. DATA ANALYSIS

To perform the data analysis, each simulated and actual demand pattern was divided into two sections. The first section contained the beginning three-fourths of the data and the second section contained the last one-fourth of the data.

No Trend or Seasonality



Trend and Seasonality



Demand Patterns Tested

Figure 4

For the simple exponential smoothing model, the optimal alpha was selected by minimizing the MAD over the first three-fourths of the data. The MAD over the remaining one-fourth of the data was then calculated and compared to the MAD for the adjusted exponential smoothing methods over the same one-fourth of the data to determine which method was the most effective. The test was also repeated using an alpha value of .20, which is a value typically used in the Navy as a generic, all-purpose value.

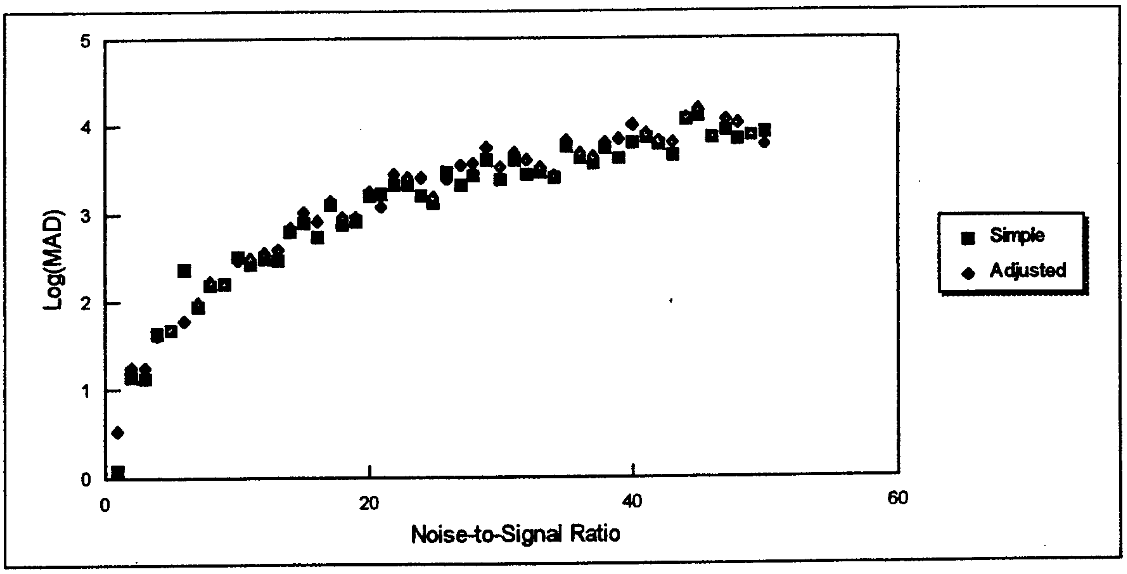
C. RESULTS OF THE FIRST TEST

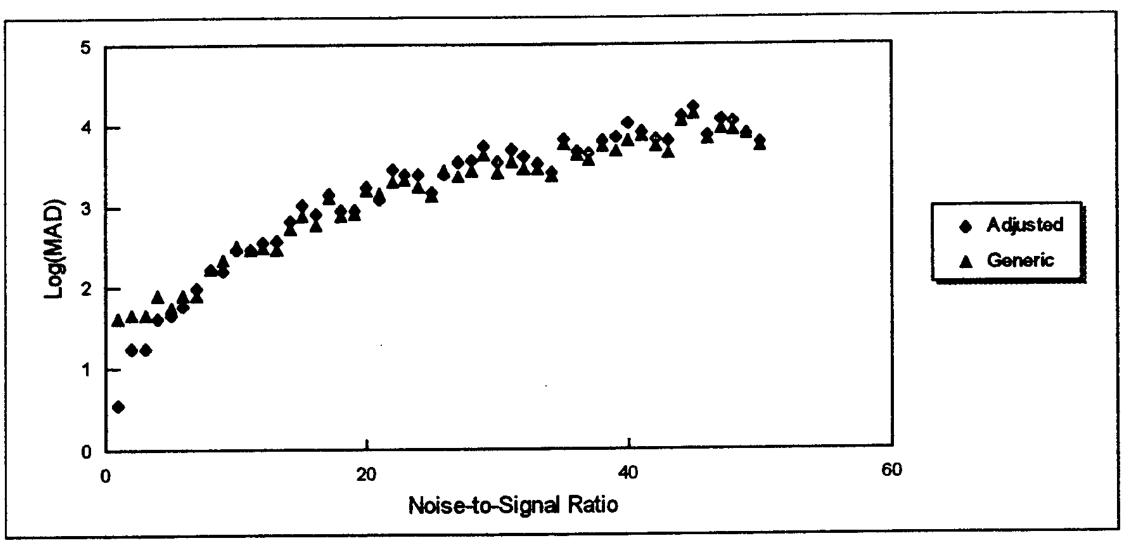
The comparison between the simple, the adjusted, and the generic alpha exponential smoothing methods indicates that the adjusted method is as good as, and in some cases better than, the simple method with an optimized alpha and the simple method with a generic alpha of .20. Figure 5 graphically illistrates each forecasting method's performance for the 50 data sets. All three methods are compared versus the noise-to-signal ratio. Since the mean value of each data set is not constant, the natural logarithm of each forecasting method's MAD value is shown so that the errors can be seen as a percentage. The average MAD value for each method computed over the 50 data sets is shown in Table 1.

	Simple	Adjusted	Generic
Log (MAD)	3.06	3.12	3.11

Average MAD for Each Method

Table 1





Simple, Adjusted and Generic Methods Compared Versus Noise-to-Signal Ratio

Figure 5

It can be seen that the results from all three methods are comparable. The flexibility of the adjusted method to react to the characteristics of the data set are particularly obvious for low values of the noise-to-signal ratio. (See Figure 5.)

D. RESULTS OF THE SECOND TEST

The comparison between the simple, the adjusted, and the generic alpha exponential smoothing methods using actual data revealed the following results.

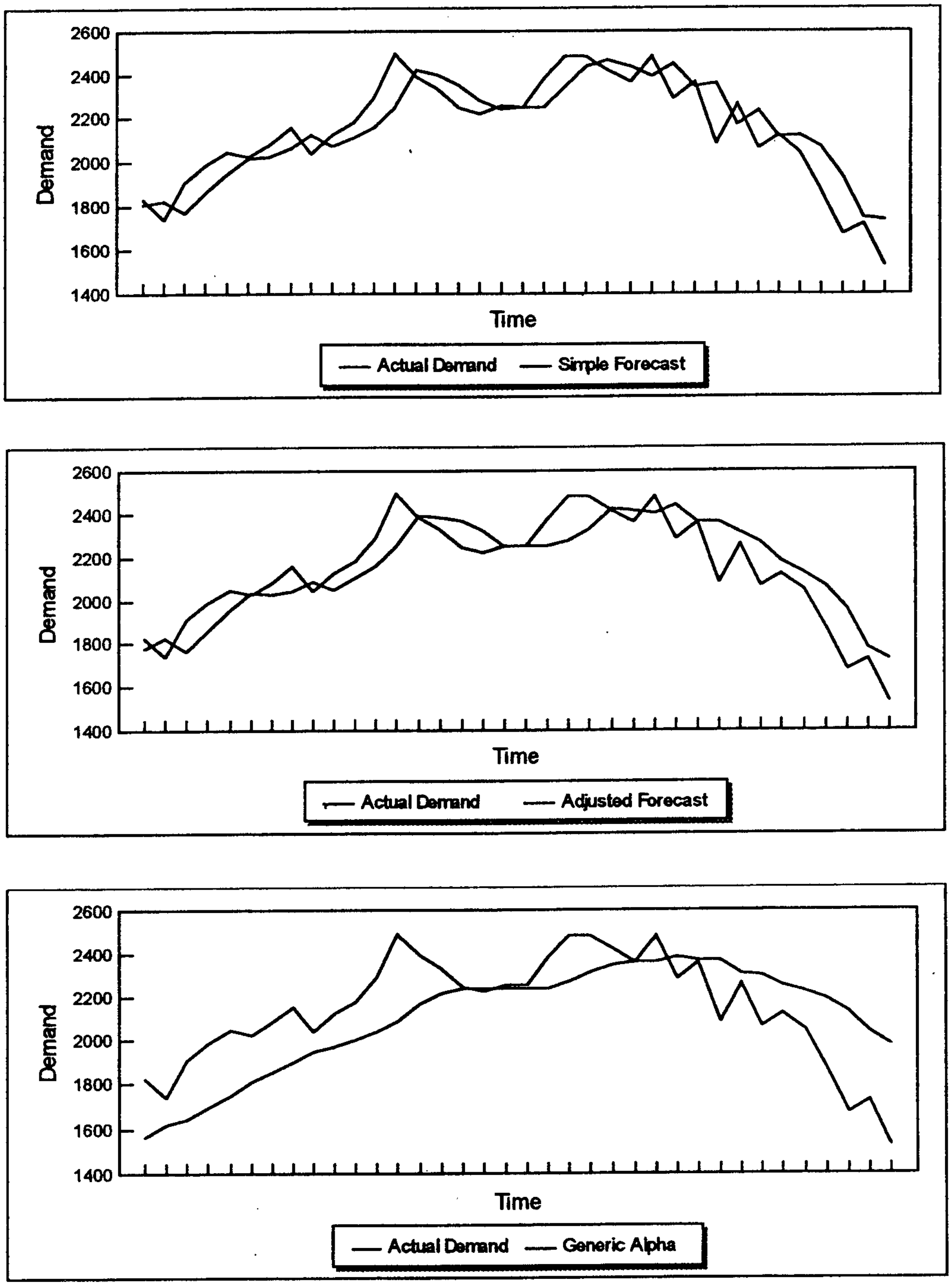
1. Demand Pattern With No Trend or Seasonal Elements

All three methods were applied to a demand pattern of 143 data points with no trend or seasonality. The MAD for the adjusted forecast method was 104 and the simple model results were 98. However, the simple method with a generic alpha of .20 had an average of 185. Figure 6 illustrates each method's performance over the last one-fourth of the data set. It can be seen that the simple and adjusted methods are comparable, yet both out performed the generic method. Table 2 tabulates the average MAD values for each method.

	Simple	Adjusted	Generic
MAD	98	104	185

Average MAD for each method

Table 2



MAD Comparison for No Trend or Seasonality Demand Pattern

Figure 6

2. Demand pattern with trend and seasonal elements

As a more rigorous test, all three methods were also applied to a demand pattern of 142 data points with both trend and seasonality. The MAD for the adjusted method was 224 compared to the simple model's MAD of 247. The generic method produced a MAD of 227.

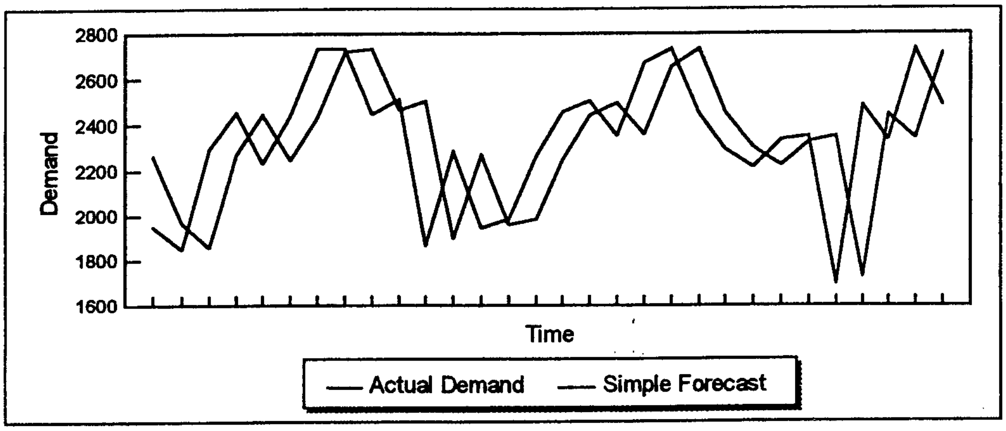
Figure 7 illustrates the performance of each method over the last one-fourth of the data set. In this test it can be seen that the adjusted and generic methods are comparable, yet both out performed the simple method. Table 3 tabulates the average MAD values for each method.

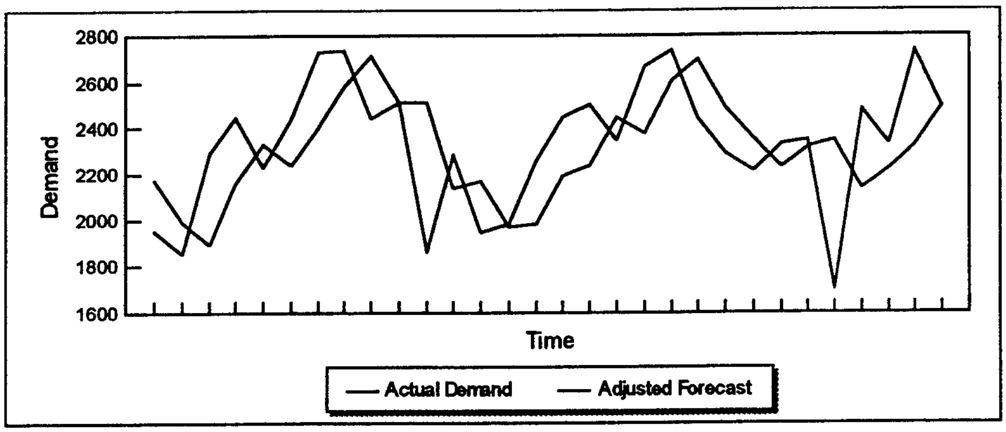
	Simple	Generic	Adjusted
MAD	247	227	224

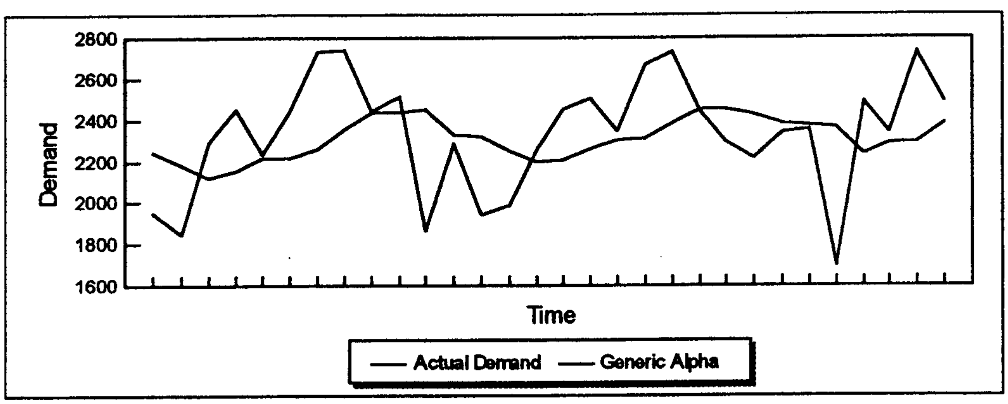
Average MAD for each method

Table 3

Figure 8 shows the magnitude of the difference between each methods performance for both data sets. The results from the data set with trend and seasonality are particularly illustrative of the appropriateness of the adjusted method. The generic method did very well since the optimum alpha value for the last one-fourth of the data happens to be .185. By luck the generic alpha of .20 is very close to the optimum value. However, the optimum alpha for the first three-fourths of the data was .965. Consequently, the simple method did poorly and did not have the ability to adapt to changes in the demand pattern.



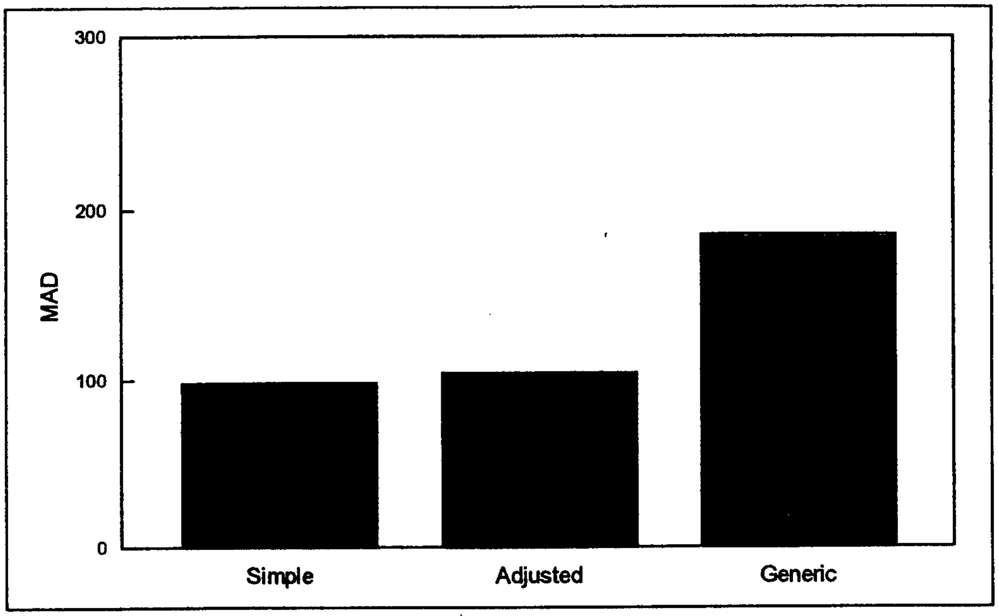




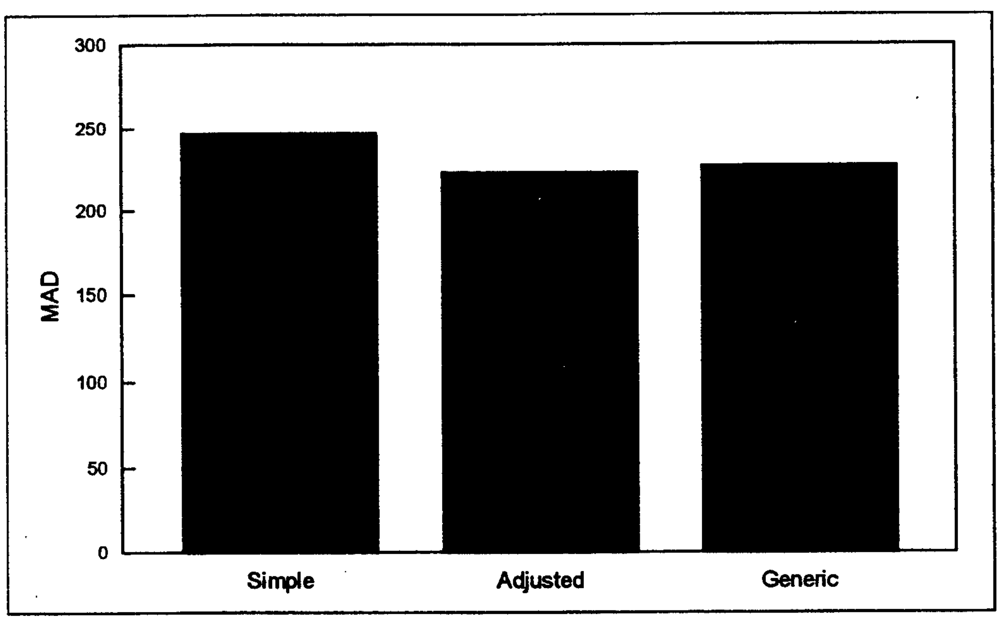
MAD Comparison for Trend and Seasonality Demand Pattern

Figure 7

No Trend and Seasonality



Trend and Seasonality



Demand Pattern Comparisons

Figure 8

E. CHAPTER SUMMARY

The adjusted exponential smoothing methods results are comparable, and in some situations superior, to the simple forecasting method with an "optimized" alpha. Yet, the adjusted method is easier to use since the smoothing constant is calculated automatically based on the behavior of the data.

Compared to simple exponential smoothing with a generic alpha, adjusted exponential smoothing can produce better forecasts by being able to adjust to the characteristics of each data set. Using the self-adjusting alpha is just as simple as using a generic alpha.

The authors opinion is that the adjusted method of exponential smoothing is a simple way to determine the smoothing constant that will minimize the overall forecasting errors and not require the storage of all previous historical data.

In Chapter IV the adjusted method of exponential smoothing is compared to the simple method under a more stringent demand scenario using data sets of lumpy demand patterns that are typical of Navy inventory demand patterns.

IV. MILITARY APPLICATION

A. CHAPTER INTRODUCTION

This chapter presents a comparison between the adjusted exponential smoothing method and the simple and generic exponential smoothing methods to answer the research question: can the adjusted exponential smoothing approach improve customer service in military inventory management through fewer not-in-stock occurances and reduced excess inventories? This analysis examines five lumpy demand patterns that are typical of many demand patterns for consumable military inventories.

B. LUMPY DEMAND DEFINED

When demand is characterized by low volume and a high degree of uncertainty as to when and at what level demand will occur, the time series is said to be "lumpy." Lumpy demand represents the condition where there is so much random variation in the demand pattern that trend and seasonal patterns are obscured. This type of demand pattern occurs in various situations: the demand pattern is dominated by large, infrequent customer orders; the demand for an item is derived from the demand for other products or services; items are withdrawn from stockrooms infrequently, but in large quantities; seasonal peaking is not consistent; and the demand pattern is the result of unusual conditions. [Ballou]

Lumpy demand patterns are difficult to predict accurately by mathematical methods due to the wide variability in the time series. In addition, lumpy demand situations have the effect of increasing the variability of use during lead time, thus increasing the size of safety stocks and consequently increasing average inventory levels. Figure 9 illustrates a lumpy demand pattern.

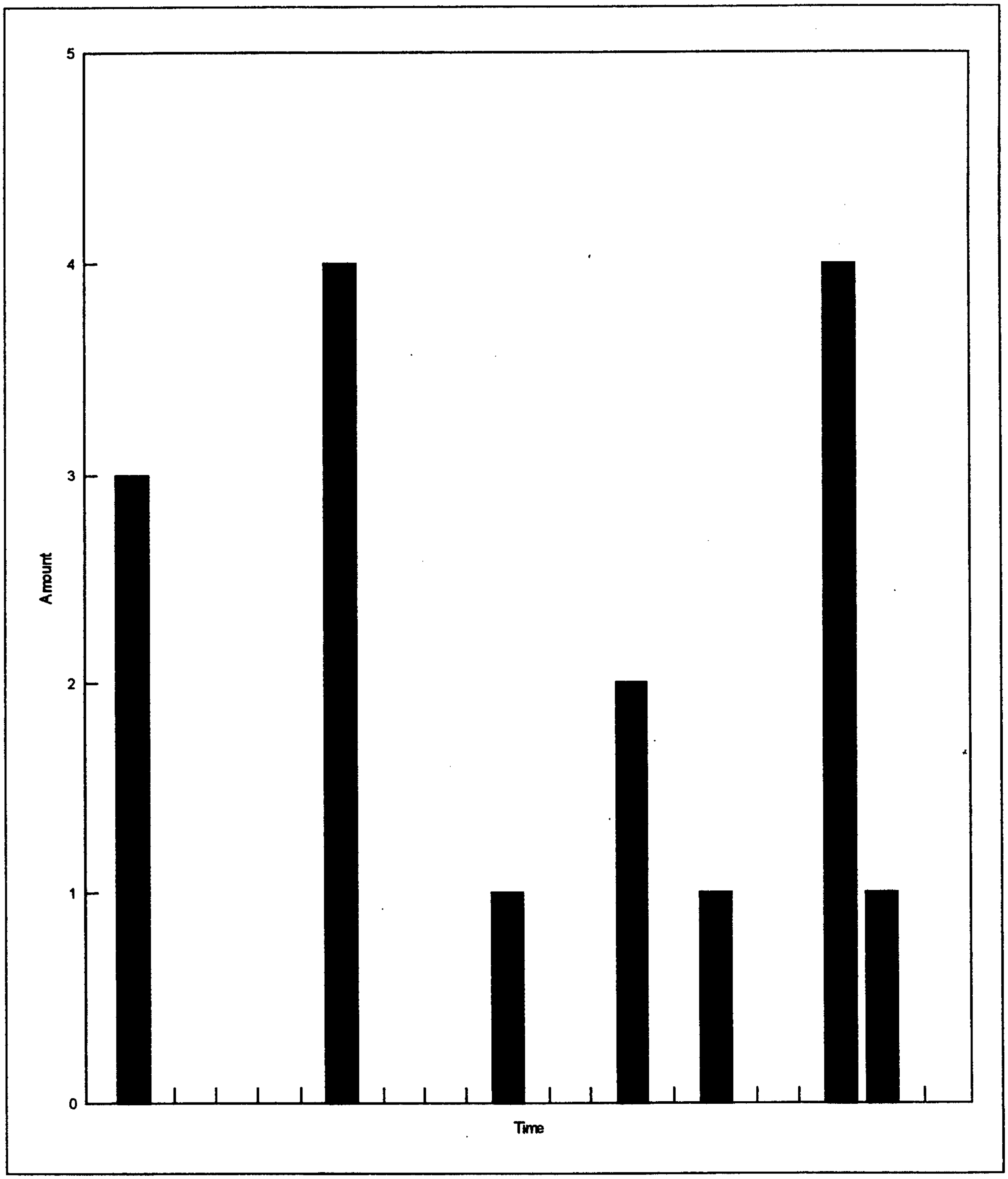
C. ROLE OF INVENTORY IN THE MILITARY

Inventory is defined as a stock of items kept on hand by an organization to use to meet customer demand. [Taylor] Virtually every type of organization maintains some type of consumable inventory. The U.S. military is no exception. The military maintains millions of consumable stock items to meet its daily operations as well as items pre-positioned for wartime contingencies. Subsequently, large inventories are built up to meet these lumpy demand patterns.

Demand forecasting for consumable items in the military is done on a quarterly basis where the alpha smoothing constant is pre-determined. This method of demand forecasting often leads to large excess inventories and numerous not-in-stock scenarios with high incidents of shortages due to forecasting errors.

D. DATA ANALYSIS

The lumpy demand analysis compared the optimal alpha and minimum MAD for the simple and generic exponential methods to the average alpha and minimum MAD for the adjusted exponential



Typical Lumpy Demand Pattern

Figure 9

smoothing method. The analysis was conducted on five simulated lumpy demand patterns containing 20 data points each. Each data set was the same as shown in Figure 9 except that the amount demanded in the first time period was respectively 4, 3, 2, 1, and 0. The results are compared in Table 4.

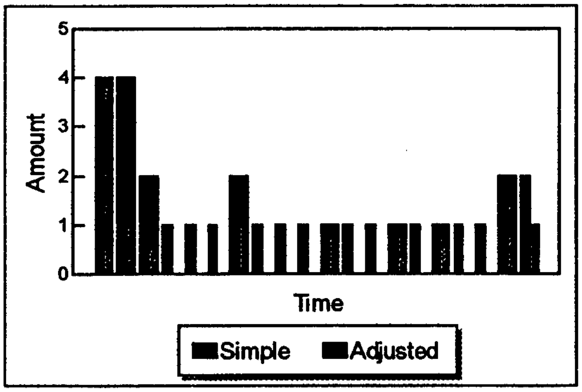
	Simple		Adjusted		Generic	
Test	Alpha	MAD	Avg Alpha	MAD	Alpha	MAD
1	.438	1.35	.845	1.25	.20	1.80
2	.376	1.30	.853	1.15	.20	1.70
3	.375	1.20	.854	1.10	.20	1.65
4	.383	1.15	.870	1.00	.20	1.50
5	.120	0.65	.878	0.95	.20	0.95

MAD for Each Method

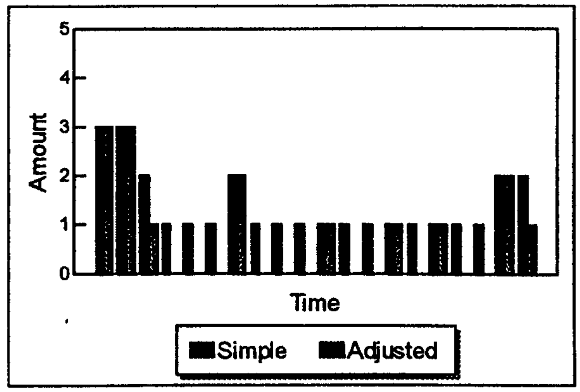
Table 4

With the exception of test number five, the adjusted exponential smoothing method performed better than the simple method based on a lower MAD. In test five, the simple exponential smoothing forecast with the minimum MAD was for the non-informational forecast of zero each period. Such a forecast might have the minimum MAD, but it is entirely useless for inventory control decision-making since nothing would ever be ordered. (See Figure 10.)

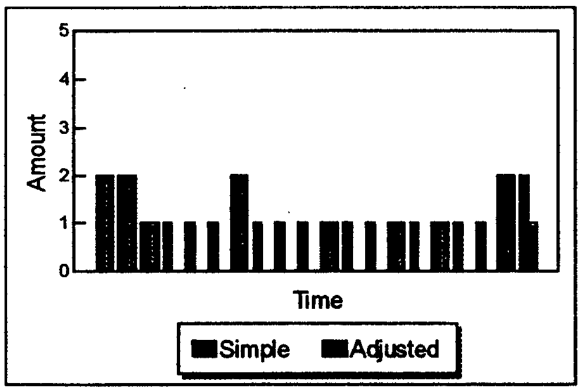
The adjusted exponential smoothing method performed much better than the generic method on the first four tests and the same for test 5. (See Figure 11.) The adaptability of the adjusted method is a significant advantage when dealing with lumpy data.



Test 1



Test 2



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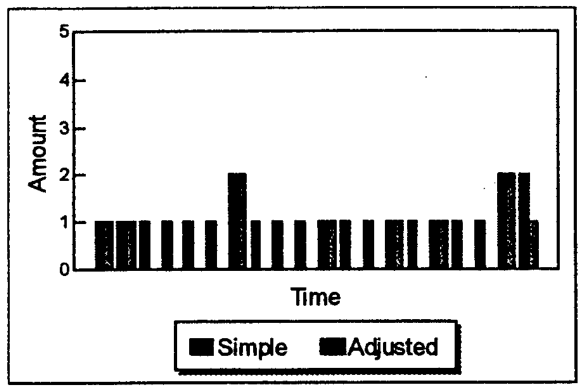

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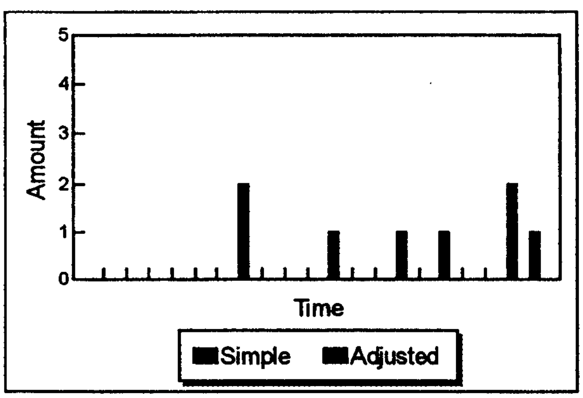
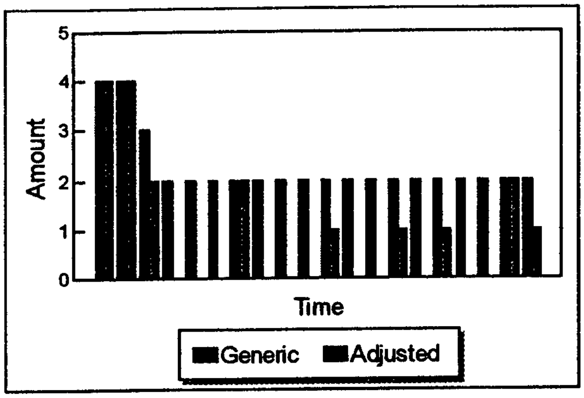


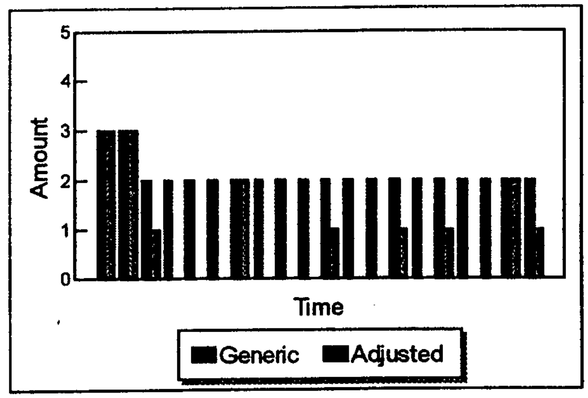
Test 5

Comparison of Simple and Adjusted Methods for Lumpy Data

Figure 10



Test 1



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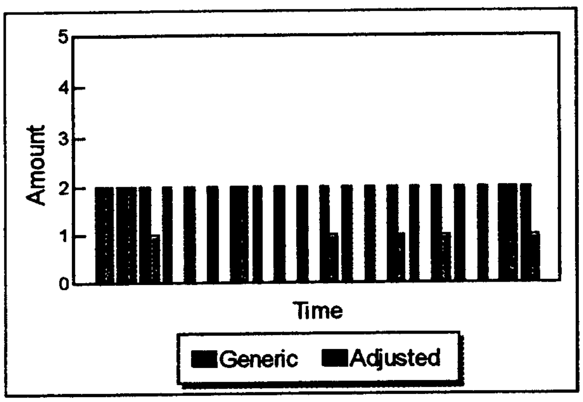

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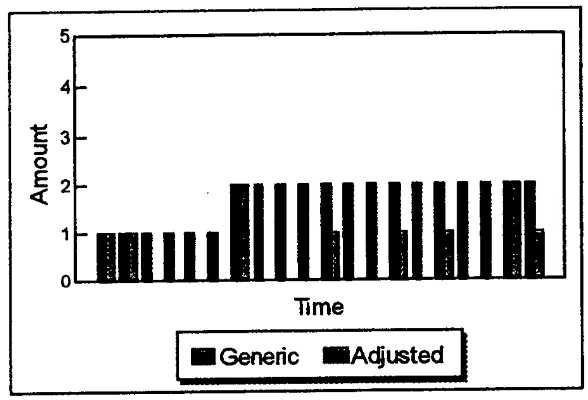
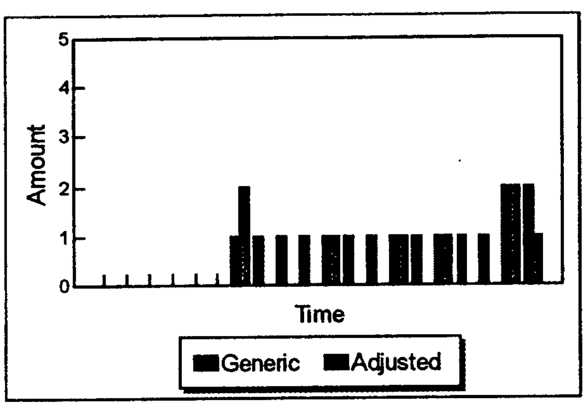


Test 4



Test 5

Comparison of Generic and Adjusted Methods for Lumpy Data

Figure 11

E. CHAPTER SUMMARY

This chapter subjected the adjusted exponential smoothing method to the most difficult inventory demand forecasting test, lumpy demand, to answer the research question: can the adjusted exponential smoothing approach improve customer service in military inventory management through fewer not-in-stock occurances and reduced excess inventories? It is the author's opinion that the adjusted exponential smoothing method could reduce not-in-stock occurances and is preferable to both simple and generic exponential smoothing methods.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The focus of this research was to determine if the noise-to-signal ratio could be used to determine the smoothing constant in exponential smoothing for inventory control. In order to make that assessment this research:

1) provided a brief overview of the underlying principles of exponential smoothing as applied to inventory demand forecasting,

2) examined how exponential smoothing can be modified by using the noise-to-signal ratio to select the smoothing constant for a specific inventory demand pattern, and

3) outlined the impact the adjusted method of exponential smoothing could have on reducing excess inventories and stockouts and thereby increasing customer service.

B. CONCLUSIONS

The noise-to-signal ratio can be used to select the smoothing constant for a given set of demand data and thereby improve inventory management effectiveness. The forecast error (MAD) tests conducted on the simulated data sets conclude that the adjusted method of exponential smoothing did as good as, and some times better than, the simple and the generic alpha methods of exponential smoothing.

This research has illustrated that the idea "that what worked in the past will work in the future" does not always hold true. Just because a smoothing constant worked well on the first part of a data set, does not mean that the same value will always work well for later data points, as assumed by the simple exponential smoothing model. In addition, this research has also illustrated that the idea that "one-size can fit all" approach to selecting a smoothing constant, as assumed by the generic alpha method, does not always produce good results either. The ability of a forecasting method to adapt to the changing characteristics of a data set can produce better results.

As is the case of the lumpy demand scenario, the adjusted exponential smoothing method did not indicate a need to reorder as often or as much as the simple method did. The end result would be minimized excess inventories, holding costs, and an increased level of customer service through fewer stockouts.

The adjusted method provides: a good forecast, minimum data storage requirement, and an automatic way to select the smoothing constant. The adjusted exponential smoothing method's forecasts were consistently comparable or better than the other methods'. Table 5 itemizes a comparison of the data storage requirements and alpha selection approach that characterizes each method.

Compared to the simple method, the adjusted method requires far less data storage and provides an easier way to select the smoothing constant.

Method	Data Storage Requirements	Alpha Selection Approach
Simple	All Historical Data	Tedious Optimization By Iteration
Adjusted	$A_t, F_t,$ and F_{t-1}	Automatic
Generic	A_t and F_t	Pre-set Yet Relevance Unknown

Comparison of Method Characteristics

Table 5

Compared to the generic method, the adjusted method requires only slightly more data storage and it provides a way to select the smoothing constant that is as easy yet one that is related to the characteristics of each particular data set. Thus, the adjusted exponential smoothing method provides all the features of a forecasting model that an inventory manager desires.

It is the author's opinion that this research shows that the noise-to-signal ratio can be an effective way to select the smoothing constant, and that the adjusted method of exponential smoothing model could lead to improved customer service levels through fewer not-in-stock occurances and reduced excess inventories.

C. RECOMMENDATIONS FOR FURTHER STUDY

The author has three recommendations for further research into specific inventory control areas:

1) additional comparisons of applying simple and adjusted exponential smoothing to actual demand data with time series

of various lengths from short to long,

2) evaluations of adjusted exponential smoothing when applied to demand data for repairable parts where an emphasis on inventory availability and short repair turn-around time are critical, and

3) computations of the savings that could be realized from reduced holding costs and shortage costs using the adjusted exponential smoothing method.

Further studies could also focus on a similar analysis of the noise-to-signal ratio as it applies to the beta (β) smoothing constant used in so-called trend-corrected exponential smoothing:

Forecast Trend = New Forecast + Trend Correction

This is written mathematically as:

$$T_t = (1-\beta)T_{t-1} + \beta(F_t - F_{t-1})$$

where

T_t = smoothed trend for time period t

T_{t-1} = smoothed trend for time period t-1

β = trend smoothing constant

F_t = exponential smoothed forecast for period t

F_{t-1} = forecast for time period t-1.

Finally, a study could be conducted to determine the effect of the noise-to-signal ratio as it applies to seasonality in inventory forecasting.

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